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Sugar—The Foundation of All Progress on Earth*

By Harold L. Lyon

Sugar is the beginning of each and every food. It is the primary source from which the food of all green plants and that of all the higher animals is derived. It is, in fact, the one most important factor responsible for the evolution of all the higher forms of plant and animal life. Man himself would never have come into existence if sugar had not been developed on earth. Now, these may seem to be rash statements, but we shall easily justify them.

Based upon your everyday experience with it, you are apt to think of sugar as something sweet to the taste and easy to take. You visualize it as the stuff which you drop into your coffee or spread on your mush, or as the syrup which you pour over your hot cakes or waffles in the morning.

Should you be asked if you could do without sugar and the products derived from sugar, you would probably say, if you answered promptly, that you could if necessary. However, should you delay your reply until you had determined just what such abstinence on your part would actually mean, you would most certainly return an emphatic "no" for an answer. Your analysis of the proposition would soon lead you to the amazing conclusion but fundamental truth, that absolutely all of the energy which you obtain from the food which you eat and the beverages which you drink is derived directly or indirectly from sugar—it has at one time been locked up in sugar. You may partake of a mixed diet including fish, flesh and fowl, cereals and vegetables, milk, tea and coffee, beer and wine, yet the energy which each supplies reached the form in which you took it by way of sugar. So, if you deny yourself sugar and all the products derived from sugar, you renounce all foods and all drinks except water. You doom yourself to a slow but sure death by starvation.

If now you follow this line of investigation until you determine the whole truth regarding the role which sugar has played in the development of man and his

*An address delivered at the sixtieth annual meeting of the Hawaiian Sugar Planters' Association, Dec. 10, 1940.

civilization, you will be forced to this most astounding conclusion: all of the energy utilized by man, except that which he gets directly from the heat of the sun and earth or obtains from water and wind power, comes to him through sugar. All of the energy which he derives from the combustible materials in our forests, in the vast coal beds of the earth, in its extensive deposits of petroleum and its huge reservoirs of natural gas, was at one time locked up in sugar.

Man obtains from his food the energy which he utilizes to heat his system, to operate his organs, to move his body about from place to place, and perform the work necessary to his comfort, pleasure and existence. What is true for man in this respect is likewise true for all other animals. The food which an animal takes into its system consists of complex, chemical compounds built up by some other organism. These represent work done and energy stored up. These complex compounds, the animal breaks down and, in so doing, releases energy which the animal in turn, diverts to its own use for the creation of heat, the building up of its own body and the doing of work. The food which an animal eats not only supplies it with materials out of which to build or repair its body but also supplies the energy required to do the work and to perform other functions essential to its own well-being.

The green plant, on the other hand, employs an entirely different method of obtaining its food and energy. Its primitive ancestors learned to produce a material, leaf green or chlorophyll, which has marvelous properties. By exposing this chlorophyll to sunlight, the plant can employ the radiant energy coming from the sun to manufacture a food out of two of the most common and widely distributed compounds in nature—carbon dioxide and water. It forces these two simple compounds together into a more complex compound and, in so doing, causes work to be done and energy to be stored up. Thus, without appreciable effort on its own part, the green plant obtains its one and only energy-yielding food. This food is sugar.

Having produced sugar, the plant uses this food very much as the animal does the food which it obtains at the expense of other organisms. The plant builds up and adds to its own living substance by combining sugar with the elements nitrogen, sulphur, phosphorus, calcium, magnesium, potassium and iron, all of which it obtains in solution in the water in its environment. All the energy expended in the fabrication of living substance out of these non-living materials is obtained by breaking down or "burning up" some sugar. All the organic compounds incorporated in plant bodies such as cellulose, starch, oils, etc., which are not actual parts of their living substance but which, nevertheless, play very important roles in the economy of plants, are made out of sugar.

A little farther on, we shall discuss the manipulation of sugar by plants and note some of the many compounds which they make out of it; so, at this point, we shall only say that sugar is not only the energy-yielding food of the green plant but is also the chief building material out of which it constructs the living and nonliving parts of its body. Sugar supplies the carbon for absolutely all of the organic compounds of plant origin.

Plants, Animals and Saprobia

The production of sugar through the employment of chlorophyll as a sunlight power plant is the most important invention that has been achieved by living things throughout the many millions of years that they have been dwelling upon the earth.

This epoch-making invention has been appropriately named "photosynthesis." It at once made available to its inventors an abundant supply of energy and unlimited possibilities for experimentation in the development of bodies or organisms of varying sizes and complexities in which this art of sugar manufacture could be carried on. This type of nutrition was adopted and used exclusively by a great group of organisms, the present day progeny of which we now speak of collectively as the Plant Kingdom.

Photosynthesis, the manufacture of an energy-yielding food out of carbon dioxide and water by means of chlorophyll, was the dominant factor in determining the line along which plants would develop and the types of bodies which they would build up. A plant simply has to pick a location where it can get sunlight, and water charged with carbon dioxide and the appropriate minerals and then remain stationary, and its food supply is assured. It does not have to move around in search of food. It merely sits still in an appropriate location and its food comes to it; as a result, plants are characteristically stationary organisms for, like all other living things, they are wont to follow the lines of least resistance.

Now, among primitive organisms there were some which learned a trick quite different from photosynthesis. It cannot properly be termed an invention, but should rather be designated a vice which became a vicious habit. These tricksters learned that they could gain a lot of energy for themselves very quickly by seizing and digesting the body of another organism, thereby gaining in a few moments all the energy that the other organism had accumulated in its lifetime. This heinous idea became the dominant ambition of a group of organisms and, in developing the idea and experimenting in the production of structures or bodies designed to carry it out, the great variety and complexity of organisms which we speak of collectively as the Animal Kingdom appeared on earth. Animals prey upon their neighbors, gaining all of their body-building material as well as their energy by this method.

As plants are plants because of the type of nutrition which they adopted, so animals are animals because of the type of nutrition which they adopted. They seize and appropriate to their own use complex compounds created by other organisms. An animal must go after its food. If it sits down and waits for it, it does not get much and is, as a result, a pretty poor animal. Locomotion is, therefore, a most essential quality in an animal. It enables it to pursue and overtake its food and it enables it to get away and avoid becoming food for some other animal. So, motility has always been a mark of perfection in animal development and animals have tended to specialize in this line. Motility has been one of the most important influences determining the types or kinds of bodies which animals would develop. There was, of necessity, a forward moving end which soon became a recognizable head. In this area were located the sense organs which enabled the animal to locate its food supply and distinguish between good and bad food; also, the mouth with which to seize its food.

Now, in contrasting plants and animals, we see that plants are plants because of the type of nutrition which they adopted and this has caused them to develop as stationary organisms and build bodies in which they can carry on to best advantage their type of nutrition. Animals are, on the other hand, characteristically motile organisms because of the type of nutrition which they adopted. They expend enor-

mous amounts of energy in the constant activities of the mechanisms which they build up as bodies.

Plants are organisms in which constructive chemical processes predominate. They create new compounds more rapidly than they use them. Animals are organisms in which destructive chemical processes predominate: they destroy existing compounds far in excess of those which they build up and retain in their own bodies. Now this contrasting of plant and animal nutrition may seem to be a matter of passing interest only. We shall find, however, that it is a matter of great importance when we come to weigh the relative economy of growing plants or animals as food for human consumption.

To lay a complete foundation for our future food researches, we should also introduce at this time a consideration of the third great group or kingdom of organisms, the development and character of which were determined by the type or method of nutrition which they adopted. In a world of plants and animals, there was bound to appear vast masses of non-living organic matter resulting from the deaths of organisms because of old age, climatic changes, catastrophies, accidents and violence. Animals, as a rule, extract only a part of the nourishment from the food which they eat and usually consume only portions of the organisms which they kill. Plants shed their branches, leaves, flowers and other organs when these are no longer useful to them. As a result of natural processes, dead organic matter would rapidly accumulate on earth and in time reach enormous dimensions. This dead organic matter represents food and energy available to any organism that might wish to use it and can employ methods of handling it. As might well be expected, certain organisms coming in contact with this abundance of non-living organic products developed methods for obtaining the materials and energy necessary for their continued existence by attacking these products and extracting therefrom the nutrients which they required. These organisms assumed the role of scavengers, living on the dead bodies and castoff products of other organisms. Their nutrition somewhat resembles that of animals in that they live on products produced by other organisms, but these scavengers do not ingest or engulf solid food but apply portions of their bodies to the solids which they digest at points of contact and then absorb into their own substance only such portions as they can use. All organisms employing this type of nutrition may be spoken of collectively as the saprobia, which term, being interpreted, means rotten life or rotten living. While numerous organisms from the higher groups of animals and plants have fallen for this easy way of obtaining food, the best known, and to us the most important, saprobiacs are the bacteria and fungi.

These organisms, world-wide in distribution, perform many operations most essential to the maintenance of a proper balance in nature. They bring about the putrefaction and decay of organic materials, thus reducing these to fertile soil. They cause the fermentation yielding alcohol and, in a similar manner, produce acetic, lactic and other important acids. They are responsible for the curing of tobacco, the making of vinegar and many other processes which man encourages to his own advantage.

The majority of the bacteria and fungi have been content to remain scavengers, but a few, having learned what they want for food and where it comes from, attack the living organisms producing it and injure or destroy their tissues in order to

supply their own needs. These vicious forms which we designate "parasites" are responsible for most of the infectious and contagious diseases to which plants and animals are subject.

Sugar—The Foundation of All Foods

The first product of photosynthesis is a simple sugar made by forcing together into a single molecule six molecules of carbon dioxide and six molecules of water with the liberation of six atoms of oxygen.

Now, plants make two types or kinds of simple sugar, the molecules of which contain exactly the same number of atoms of carbon, hydrogen and oxygen, but with these atoms put together in different patterns. These two types of simple sugar differ from each other much as your right hand differs from your left hand—both hands have the same number of digits but the digits are not identically arranged—one hand being the mirror image of the other.

The two kinds of simple sugar are known as dextrose and levulose, also as glucose and fructose and, in simpler language, as grape sugar and fruit sugar.

dextrose = glucose = grape sugar
levulose = fructose = fruit sugar

Plants can convert dextrose into levulose and levulose into dextrose, the change back and forth being accomplished with no loss of sugar—just as a glove for the right hand, when turned inside out, becomes a glove for the left hand.

By combining or condensing varying numbers of molecules of dextrose into a single large molecule, many plants make multiple sugars each of which has specific properties. Certain plants also, in a similar manner, make multiple sugars out of levulose and numerous plants combine dextrose and levulose in equal amounts to make sucrose or cane sugar, which is our common table sugar. One of the most important multiple sugars is starch which is made by combining a number of glucose molecules from each of which one molecule of water has been extracted.

Many plants find it convenient to transform glucose into starch for storage purposes because starch is insoluble in water, while glucose is very soluble and readily diffusible through cell walls and, consequently, not so easily retained in tissues. Plants which employ starch for storage purposes convert it back into glucose when they wish to move it about in their bodies or to use it for food.

Another important multiple sugar made by all green plants is cellulose, which has the same chemical formula as starch but, because of the organization of its molecule, differs materially from starch with respect to properties. Cellulose is the building material out of which the solid parts of the plant body are molded. It is the primary and chief constituent of all woods. Plants are unable to convert cellulose back into glucose and animals are unable to digest it. Many of the saprobiacs, however, and particularly the wood-destroying fungi, make cellulose their chief food from which they derive organic materials for building their own substance and energy for doing the building. Some animals, by cultivating cellulose-digesting bacteria in their alimentary canals, are able to derive nutrients and energy from cellulose.

The simple and multiple sugars all contain hydrogen and oxygen in the same proportion as these elements occur in water and, as they are composed of carbon and water, they are spoken of collectively as carbohydrates.

Living substance or protoplasm we have found is a compound or complex of compounds in which ten or more elements are incorporated. Among these elements, nitrogen plays a most important and influential part and the organic complexes in which it is involved through the activity of protoplasm are known as proteins. Plants employing sugar as a source of carbon and energy can take up inorganic nitrogen and combine it with other elements to make protein. Many saprobiacs also have the ability to fabricate protein out of inorganic nitrogen and carbohydrates. The protoplasm of animals, however, does not possess this ability, but must get the nitrogen for its protein from proteins made by plants, by saprobiacs or by other animals.

The fats, which are extremely complex compounds composed of carbon, hydrogen and oxygen, play an important rolè in the vital economy of both plants and animals. Fats are made out of carbohydrates or out of materials derived from carbohydrates by the protoplasm of both plants and animals. In the making of a fat, the equivalent of numerous molecules of sugar are condensed into a single, large molecule with the elimination of considerable oxygen. Fat is a concentrated food and is employed for the storage of energy by both plants and animals. Plants make all of their own fats out of sugar but animals, feeding upon other organisms, make use of the fats as well as of the carbohydrates and proteins of their victims.

We are now in position to discuss briefly the sources of human food and the economics of its production. The essential constituents of food for a normal human being are carbohydrates, proteins, fats, vitamins and minerals. It is customary, however, to prescribe a human diet in carbohydrates, proteins and fats only, for the raw materials selected to supply these three major ingredients should also carry adequate supplies of vitamins and minerals, these latter being required in comparatively small quantities. It is also customary to measure the value of a food in terms of its fuel or caloric value, the unit being the calorie. Giving due consideration to the foods man is accustomed to eating, dietitians tell us that in the properly balanced diet of an adult human being, carbohydrates should supply about 65 per cent of the total caloric value; proteins, around 10 per cent; and fats, the remaining 25 per cent.

Carbohydrates, we have found, include simple and multiple sugars. Simple sugars, when taken as food, are absorbed directly into the blood, there to become immediately available as a source of energy. All multiple sugars, however, must be hydrolyzed or reduced to simple sugars in the process of digestion, for it is only when they are in the form of simple sugars that they can be utilized by the human system.

Sucrose or cane sugar is easily reduced to glucose and fructose, while starch is reduced to glucose with somewhat less alacrity. The fallacy of the oft-repeated statement that starch is less fattening than sugar should be readily apparent, for starch is reduced to sugar in the body before it can be utilized. When you eat starch, you are supplying your body with sugar.

Man still ingests the major portion of his carbohydrate food in the form of starch. This is undoubtedly due to the fact that starchy foods such as wheat, rice, corn and potatoes have in the past been more readily available to him than plant products containing sugar. With sugar now obtainable at a very low cost, he might

well eat more sugar and thereby reduce the strain imposed upon his digestive system.

Man can obtain all of the protein which he needs from plants alone or from animals alone. This is readily understood, for, in the last analysis, all animal proteins are derived from plant proteins. As a rule, man prefers to so arrange his diet that he gets some proteins from animals and some from plants. Man does not convert the protein taken as food directly into the proteins of his own body, but must first digest these food proteins into simpler nitrogenous compounds which can be absorbed into, and transported by, the blood. These simpler compounds may then be extracted from the blood by the protoplasm at any point in the body and used to build new proteins. There is no substitute for proteins in man's diet. These compounds are the only source from which he can obtain nitrogen, and nitrogen, as we have already found, is a most essential element for the building and repairing of protoplasm.

Fats in the human diet are equivalent to concentrated carbohydrates for, like carbohydrates, they supply energy, but much more of it per unit of weight. A pound of fat will yield more than twice as many calories as will a pound of sugar. Some animals flourish on carbohydrates without the addition of an appreciable amount of fat, but man has become so accustomed to including in his diet fats produced by other organisms that he is unhappy if deprived of them. It would be quite possible, however, for him to supply his total requirements in materials and energy with carbohydrates alone; no part of his food need be in the more concentrated form of fats. Since one pound of fat in the diet is equivalent to somewhat more than two pounds of carbohydrate for the production of fat in the human body, it follows that a man can most readily control his weight by regulating his intake of fat. To get fat, he should eat fat and to reduce his weight, he should restrict his intake of fat. It should be obvious, therefore, that while sugar in the diet may help to make a person fat, it is apt to do so only when accompanied by plenty of fat.

An expert of the United States Department of Agriculture writes:

> "Fat is commonly thought of as a source of energy in the diet. A given weight of fat has more than twice the energy value of the same amount of carbohydrate or protein. Hence those who wish to reduce or to add weight should reduce or increase the fat content of the diet first."

It should now be obvious that all of the energy supplied by any food—be it carbohydrate, protein or fat—can be traced back to sugar. The cost of a food in nature's economy may be measured by the energy in that food plus the energy expended in its fabrication. Since sugar is the energy source for all foods, the cost of a food to nature should be measured in terms of sugar. To begin with, sugar produced by plants is in itself the most economical food, for it is the primary organic compound, the energy of which is derived directly and entirely from sunlight. The further a food is removed from sugar, the more energy has been expended in its production. Food products of plant origin are derived directly from sugar made by the plants which supply the products and, hence, a minimum of energy is consumed or expended in the transformation of sugar into these products. Food products from animals, however, represent an enormous expenditure of energy in their

production for, as we have previously noted, animals are organisms in which destructive chemical processes predominate—they destroy, in existing compounds, many times the weight of the compounds which they build up and retain in their own bodies. Beef, for instance, furnishes us with protein and fat, but an animal supplying it consumes the equivalent of at least thirty pounds of sugar for every pound of beef which it yields upon slaughter. This means that fully 50 calories of energy derived from digestible plant products were expended by the animal for every calorie of energy which we obtain from its meat. To be sure, we are able to feed cattle on certain plant products that are not suitable for human consumption and, by so doing, recover a small amount of the energy which these products represent. This is a laudable procedure but when we feed to beef cattle products that are themselves suitable for human consumption, we are pursuing a most uneconomical course. Take yeast, for an example: should we use it for feed or for food? This prolific saprobiac thrives in a solution containing sugar and the more common inorganic salts. It feeds on the sugar and, picking up the necessary nitrogen and mineral elements, builds up new protoplasm, growing at a prodigious rate. The yeast organism does not construct a complicated body but merely clothes its living substance with a thin membrane. A mass of yeast, therefore, is little more than a mass of protoplasm and when we dry this mass, it is largely protein, for protoplasm, we have found, is essentially protein. When growing in a sugar solution, the yeast organism breaks down the sugar into alcohol and carbon dioxide and builds in its own body protein and fat, so the culture of yeast in a sugar solution yields three valuable food products—protein, alcohol and fat. Under favorable conditions, which are easily maintained in any climate, a crop of yeast grows to maturity in less than 24 hours, so it is quite possible to harvest a crop every day in the year. At a pilot plant in Honolulu, all the details of yeast production as a commercial crop have been worked out. The dry product is 50 per cent protein and very rich in the vitamins of the "B" complex. It is quite palatable and a number of people have for some time been eating it regularly to determine its value as a source of protein in the human diet. Their reactions are all very favorable. A few people, suffering from nutritional disorders, are also being supplied with this yeast and some of them report remarkably pleasing results. One man who had always been emaciated gained 20 pounds in a few months and thereafter maintained a normal weight. A diabetic, after eating yeast regularly for some time discovered that his tolerance for carbohydrates had greatly increased. He enjoyed this increased tolerance only so long as he included yeast in his diet. Naturally, he eats yeast regularly if he can get it.

Strange to say, this pilot plant is being promoted with the idea of producing yeast, not for food for human consumption, but for feed for livestock. Up to the present time, most of its output has been used in feeding experiments with cattle, hogs, poultry, etc. The results of these experiments, I am privileged to report, favor the use of yeast as a source of protein. However, since this yeast has proved to be a good protein food for humans, it is poor economy to feed it to beef cattle, for it will be necessary to feed at least 10 pounds of yeast protein for every pound of protein recovered in beef.

Sugar—The Source of All Motor Fuel

If all the animals on earth were separated from all of the plants and plant products on earth, the animals would very soon die and disappear from the face of the earth. Animals are absolutely dependent on plants for their food. Certain animals, it is true, prey almost entirely upon other animals and many animals subsist upon a mixed diet of animal and plant materials, but the great majority of animals eat plant material only as their food. Animals which become the food of other animals are, themselves, plant feeders or feed upon animals that are plant feeders. We might very possibly cite special cases where flesh-eating animals eat flesh-eating animals that eat flesh-eating animals in a sequence of considerable length, but this sequence would eventually end with an animal that fed exclusively upon plants. There is only one possible conclusion to our investigation along this line: all animals derive the energy with which they operate their bodily mechanisms directly or indirectly from plants. Traced to its ultimate source, it was energy locked up at one time in the bodies and products produced by plants and these, we have found, have their origin in sugar.

That the vast coal beds of the world are the residue or remains of plants which grew upon earth in bygone ages is too well known to require discussion here. There may be some grounds for debate as to whether the world's deposits of petroleum and natural gas were derived from animal or from plant remains or from a combination of animal and plant remains, but such questions need not concern us in our present thesis for, whatever the correct answers to these questions may be, we have already established the fact that all of the energy represented must have been accumulated in the first place by plants and they garnered it from sunshine and locked it up in sugar.

The facilities, comforts and conveniences of modern civilization are made possible by the extensive mechanized industries and transportation systems which man has built for himself. To operate these industries and systems, he is expending vast amounts of energy which he derives from coal, petroleum and natural gas. Now, these materials are the remains of organisms which lived upon the earth in bygone ages and the energy which they now yield reached the earth as radiant energy where it was captured by green plants and locked up, first as sugar, then later transformed into other organic products.

The deposits of coal, oil and gas, on which the perpetuation of our modern civilization so largely depends constitute inherited capital which is not being replenished. Its ultimate exhaustion is certain and too imminent for pleasant contemplation. When this inherited capital is gone, our only source of fuel will be products derived from current crops and the serious question is: how much fuel can current crops provide after they have supplied our food requirements?

To gain some knowledge of the problems which man must solve in order that his mechanized industries and transportation systems may continue, let us examine some of his present-day expenditures in energy-yielding products and the sources from which he draws them:

Petroleum is today our most important and most patronized source of energy, so we will examine the petroleum situation. There is now being extracted from this earth, each year, over 2 billion barrels of petroleum. Crude petroleum yields at

least $1\frac{1}{2}$ billion gram calories per barrel, so 2 billion barrels will represent 3 quintillion gram calories of energy. Now, a very generous estimate of the energy which might be recovered by man and converted to his own use from the organic compounds made by all the plants on earth during a single year would be 200 quadrillion gram calories. It follows, therefore, that when man consumes 2 billion barrels of petroleum in a year, he is expending at least fifteen times as much energy as he could recover from that captured by all of the plants on earth in that same year. The inevitable result of this prodigality is too obvious to require discussion.

Petroleum geologists, who have made a careful study of the situation, estimate that at the present rate of consumption the world's visible supply of petroleum will be exhausted in another twenty years while the most optimistic petroleum exploiters, after making due allowance for the new oil fields which they expect to discover, do not claim that the world's supply will last more than forty years. To us, the most appalling feature of this situation is the fact that the United States is now providing 60 per cent of the world's petroleum. It is dissipating one of its most valuable and most vitally important natural resources in a most stupid and reckless manner. By so doing, it is inviting, if not insuring, a national calamity of unprecedented proportions. Contemplate, if you will, the predicament of the United States when, its own petroleum supply exhausted, it has to buy oil from other countries. Under such conditions, where will we be in case of war? Should not the conservation of petroleum be made a national issue?

When the impending petroleum shortage is mentioned, it is often dismissed with the reassuring statement that: "when petroleum is gone, we will derive our liquid fuel from coal and oil shales of which we have large deposits." Quite true, we can obtain liquid fuel from these sources, but its energy will cost us many times the present price of that supplied by petroleum, as we shall have to expend much energy to bring about the conversion. The obvious result will be a very rapid consumption of our inherited capital in coal and oil shales, leading to their speedy exhaustion. Another oft-repeated assertion deserving our attention is that when gasoline is no longer available, or becomes too expensive, we will use alcohol instead. This sounds reasonable, for alcohol has proved to be an excellent substitute for gasoline in internal combustion engines. However, if America was deprived of gasoline today, alcohol could never be made available in the country in sufficient quantities to fill its place. Alcohol is derived from other organic compounds all of which must have had their origin in sugar. It represents radiant energy which was at some time captured by green plants. Through fermentation, we obtain alcohol from carbohydrates; by distillation, from wood; and by synthesis, from petroleum. The production of alcohol, therefore, necessitates the consumption of existing food or fuel and, consequently, does not in any way increase our available supply of energy. To be sure, it does afford us an opportunity to convert surplus food into a useful fuel, an opportunity which in this country is at the present time being criminally neglected.

Our nation annually consumes about 22 billion gallons of gasoline. If we took absolutely all of the fermentable crops produced in one year in the United States and converted them into alcohol, we should obtain far less than half of 22 billion

gallons, and a gallon of alcohol has considerably less energy value than a gallon of gasoline.*

Now, we shall always require at least 80 per cent of our fermentable crops for food, hence, not more than 20 per cent will be available for alcohol production, so we can never expect to annually produce more than 2½ billion gallons of alcohol for fuel purposes from our surplus crops unless we radically modify our agricultural industry as to acreage, methods of culture and crops grown.

American Farming Industry Strangled by Unfair Competition

During the first half century of our nation's existence, the farmers of the country produced not only all of the plant food consumed by its human population but also supplied with their crops the energy which moved all conveyances overland within its boundaries. All passengers and all freight were moved by animals which derived their energy from feed provided by crops of the day. Shortly after our country had passed its fiftieth birthday, however, railroads began to displace animal-drawn conveyances over the most profitable routes and by the time our country had passed its seventy-fifth birthday, the railroads had captured a very large part of its freight and passenger traffic. The railroads expended vast amounts of energy to move their trains but they derived this energy from coal, not from the current products of the farm.

At the beginning of the present century, the farmers of the United States still supplied with their crops the energy that moved most of the freight of the country over at least a small part of its journey from its place of origin to the point at which it was consumed. The railroads and steamships made the long hauls, to be sure, but a very large part of their freight was hauled to and from the depots and wharves on animal-drawn trucks and drays. Likewise, transportation of all products from the farms and the distribution of all commodities within the cities were accomplished with horse-drawn carts and wagons. Coaches, hacks, cabs and buggies carried passengers over country roads and city streets. Horses and mules furnished all the motive power on the farms. In those days, millions of draft animals were used daily throughout the country and millions of acres of farm land were continuously employed for the growing of crops to feed these animals and supply the energy which they expended. During the past forty years, however, draft animals have been almost entirely replaced by internal combustion engines. All types of horse-drawn vehicles have disappeared from our city streets and now are rarely seen even on our country roads. The majority of our farmers have reduced their strings of horses and now use motor trucks and tractors on their farms.

Automobiles, buses, trucks and tractors are propelled by internal combustion engines and the energy operating these engines is derived from underground de-

* From data prepared and published by experts in the U. S. Department of Agriculture (Miscellaneous Publication No. 327, page 43), we learn that: if all the fermentable crops, Apples, Apricots, Barley, Buckwheat, Carrots, Corn, Dates, Figs, Grain Sorghum, Grapes, Peaches, Pears, Plums, Potatoes, Sweet Potatoes (including Yams), Rice, Rye, Sorgo Sirup, Sugar Beets, Sugar Cane (for sugar), Sugar Cane (for sirup), Sugar Cane Molasses (blackstrap), and Wheat produced in the United States in the year 1935 had in their entirety been converted into anhydrous alcohol, the total yield would have been somewhat less than 9,631,000,000 gallons.

posits of oil and gas and not from the crops of modern farms. As a result, millions of acres of land which, in 1900, produced crops to feed draft animals are now idle or contribute to an unwieldly surplus, and hosts of farmers' sons who should be gainfully employed cultivating these acres have been compelled to leave the farms and seek a livelihood elsewhere. The displacement of draft animals by internal combustion engines has accomplished the displacement of farm-grown feeds by petroleum products. The crops of today were made to compete with the crops of bygone ages. These ancient crops were raised, garnered and processed by nature without human assistance. Consequently, they carry no charges for taxes paid on the land on which they grew, no charges for labor expended in planting and harvesting, and no charges for concentration and storage. Petroleum and natural gas are removed from the earth at little expense and are sold at such ridiculously low prices that present-day plant crops cannot begin to compete with them as a source of energy.

Clearly, the farming industry is the victim of the most unfair and devastating competition that any major industry has ever had to meet. The huge transportation-energy market, which at one time it alone supplied, has been invaded by the petroleum industry which, in a few short years, rendered farming unprofitable and drove millions of men away from the farms. Thus, the unrestricted exploitation of America's petroleum supply has not only wrecked the farming industry but has, at the same time, seriously disrupted the social and economic life of the country.

While the progressive destruction of the farming industry has been constantly apparent and the factor bringing about this destruction easily discerned, our national law makers have taken no effective steps to succor the farming industry by checking the unfair competition to which it was subjected by the petroleum industry.

There are many ways in which the two industries could be maintained upon an equal and fair basis, but the most logical method would be to require that all motor fuels sold within the United States contain a certain percentage of anhydrous alcohol. This percentage should be such as would require the conversion of all possible crop surpluses into alcohol in order to attain the necessary volume. It should be possible to raise this percentage to such a point that it would call for the intensive cultivation of millions of acres of land now idle or producing only a small part of their potential yield. It would also return many idle men to agricultural pursuits and to the handling and processing of farm products. It would go a long way towards curing our greatest national malady—unemployment—and finally it would be a most decisive and profitable step in the conservation of our natural resources.

While considering the plight of the American farmer and the unfair treatment accorded him by our government, we should call attention to the fact that two important products of American farms, alcoholic beverages and tobacco, are unmercifully taxed. Why should these products of modern farms be made to contribute so heavily to the support of government, while coal and petroleum, products of the untaxed and unworked farms of bygone ages be allowed to escape with light taxes?

We Should Increase Our Sugar Production

In order that our children and our children's children may experience the blessings, comforts and conveniences which we now enjoy, there must be available to them an enormous amount of convertible energy. By our reckless consumption of coal, oil and gas, we are dissipating the world's reserves and thereby depriving posterity of its rightful share in this inheritance. Our interest in, and obligations to, posterity and to our country demand that we temper our consumption of coal, oil and gas by gathering with our current crops all of the radiant energy possible. Instead of restricting production on our farms, we should take effective steps to increase production. We should select for cultivation crops that yield a maximum of convertible energy. Instead of paying farmers a bonus for curtailing production, we should insure them adequate returns for maximum crops. There would never be a surplus under proper administration.

In selecting crops to be grown on American farms, we should first assign an adequate acreage to crops essential for food. Having done this, we should then select for cultivation in each locality the crop that, growing in that locality, will yield the largest amount of convertible energy per acre. In the following table we reproduce data supplied by the United States Department of Agriculture on which such an allotment might well be made.

AVERAGE YIELD OF 99.5 PER CENT ALCOHOL PER ACRE

Material	Gallons	Material	Gallons
Sugar cane (Hawaii)	444.5	Pineapples	78.0
Sugar beets	287.0	Rice, rough	65.6
Sugar cane (Louisiana)	268.0	Pears	49.3
Jerusalem artichokes	180.0	Barley	47.9
Potatoes	178.0	Apricots	41.0
Sweet potatoes	141.0	Oats	36.3
Apples	140.0	Grain sorghum	35.5
Dates, dry	126.0	Buckwheat	34.2
Carrots	121.0	Wheat (all varieties)	33.0
Raisins	101.7	Figs, fresh	31.5
Yams	94.0	Figs, dry	29.5
Grapes (all varieties)	90.4	Sorghum cane	26.4
Corn	88.8	Rye	23.8
Peaches	84.0	Plums (non-prunes)	21.8
Prunes, dry	82.8		

A glance at this table will convince anybody that every acre in the United States which will grow sugar beets or sugar cane should be devoted to these crops, for they lead all others in yields of convertible energy per acre.

We Might Store Sugar Instead of Gold

It is most certainly true that the world's population is now consuming each year in food and fuel, many times as much energy as is being accumulated on earth by its crops during that same year. If this is allowed to continue, consider the plight of man when the supplies of petroleum and coal are exhausted. He may be able to feed himself but he will have no great surplus of organic materials to convert into fuel and it will be too late to build up a supply for this purpose. It would only

be reasonable foresight, therefore, for the present-day nations to store up organic compounds against that time in the not-distant future when they will be sorely needed.

The United States already has a very large part of the world's available gold stored in its strong chambers. If, now, other nations should pay their outstanding debts to the United States in gold, this country would soon have in its possession practically all of the world's mobile supply of this precious metal. When this condition had been arrived at, it would then be possible for all other nations to forbid the circulation of gold, much as our own country has done, and the United States would find that its once precious metal had become an almost useless metal for, in case of an emergency such as war or famine, its gold could not be converted into food, fuel or even good ammunition.

Now, supposing that instead of storing only gold, we should store some sugar. Then, in case of an emergency, our sugar reserve would supply us with food of the highest quality, efficient fuel and even high explosives. The sugar itself would be the very best carbohydrate for human consumption and by feeding some of it to yeast, we could obtain an excellent protein and some fat to round out our food requirements, at the same time recovering alcohol for liquid fuel. Pure sugar, if properly stored, will keep indefinitely and we need not fear that we might accumulate too large a reserve for, when the world's supply of petroleum is exhausted, the demands for sugar will be far in excess of any supply that it will have been possible to accumulate in the world before this crisis overtakes it.

While the storage of vast amounts of sugar is feasible, it would be far better economy to convert each year all sugar not needed for food into fuel alcohol and arrange for the immediate consumption of this alcohol in place of its equivalent in gasoline. Petroleum is already safely stored in underground reservoirs provided free by nature and we should take steps to retain a supply in these reservoirs just as long as possible.

Summary

All plants, gathering energy from sunlight, manufacture out of carbon dioxide and water their one and only energy-yielding food—SUGAR.

All animals and all saprobia derive their energy-yielding food directly or indirectly from plants and consequently from sugar.

All of the energy which we obtain from coal, oil and gas was accumulated in the very remote past by plants and they garnered it from sunshine and locked it up in sugar.

Agriculture, the cultivation of plants for the production of sugar and compounds made therefrom, is the very foundation on which civilization has been built.

Petroleum products, derived from the untended and untaxed crops of bygone ages, have displaced the products of modern farms in the transportation-energy market and by so doing all but wrecked American agriculture.

Civilization of today is squandering the latent energy inherited from the past in a most heedless and reckless manner; drunk with cheap power, it is fast riding to a fall.

Our obligations to our country and to posterity demand that, each and every year, we gather with our crops all of the radiant energy possible.

Sugar beets and sugar cane are far superior to all other crops in ability to gather radiant energy and render it available to man in food and fuel.

In closing we wish to say that all of the data presented in this thesis may be found in current publications and more particularly in those issued by the United States Department of Agriculture.

All of this information has long been at the disposal of our National Government yet, in recent years, it has enforced a curtailment of our crops, thus preventing the acquisition of large amounts of energy which we might have garnered with these crops and added to our resources but now have lost forever.

Internal Moisture Relations of Sugar Cane—The Selection of a Moisture Index*

By Harry F. Clements and T. Kubota

In attempting to arrive at a proper approach to an irrigation program, two general avenues are open. One involves an effort to evaluate all of the factors which affect the transpirational requirements of a given crop consisting of soil, atmosphere, and plant factors. A program based on such a multitude of factors, many of which necessarily are unknown, seems destined for such involved complications as to render it impractical. The second, proposed earlier by the senior author, is based on the simple hypothesis that the moisture level of a crop at any one time is the result of the interplay of all internal and external factors affecting the water relations of the plant as integrated by the plant itself. *In this, all of the difficult and complicated calculations involved in the first approach are automatically taken care of by the plant. To use this method requires a tissue to be known as a Moisture Index which can be collected periodically and its moisture level determined. By associating the various levels of the Moisture Index with the physiological behavior of the plant, the grower will be able to provide water as needed by the crop.*

Data obtained from eight plots of sugar cane, four of which were grown at Waipio and four at Kailua, were examined for a suitable Moisture Index. The organ selected is made up of the sheaths of the elongating cane leaves. Satisfactory correlations were found between the moisture content of this organ and the active growing tissue, the whole of the green top of the plant, as well as the millable cane. Curves and straight lines were constructed for these relationships and their predictive values determined.

Introduction

Curiously enough, water, which makes up the greatest part of a plant, has received far less attention from students of growth processes than have such materials as specific growth substances which occur in the merest of traces. Most of the attention of research workers concerned with moisture relations has been directed toward the relation of water to soil (2), the nature and availability of water in soil (21), cultural practices designed to reduce water loss both through evaporation and runoff. Only casually has the plant received attention, and this essentially has been directed toward such empirical results as the wilting of plants in relation to soil moisture, and yields obtained in relation to irrigation frequency and amount. Some effort has been directed toward the selection of crops or varieties with low transpirational requirements.

Until recently practically nothing has been done to understand the positive effects of transpiration (5) nor have the internal moisture relations of plants received objective attention. Too many investigators have subscribed to the quaint

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view, even recently urged, that transpiration is essentially a harmful process (12), little realizing that it is necessarily the process which on the one hand augments the absorption (13) and translocation of materials (8) essential to the physiological reactions of terrestrial plants, and on the other hand enables the plant to safely project itself into a high energy environment (23) so finally necessary to rapid synthesis and growth (9, 17).

It should be obvious to any observer that in regions where moisture in a soil is less than sufficient for the growth of a given crop, it superficially appears as though transpiration is the cause of the failure of the crop. Actually, however, the direct cause of the failure is the selection of a crop which morphologically and physiologically is adapted to an environment either of lower energy levels or higher moisture levels or both. On the other hand, plants which are so adapted to grow in a high-energy atmosphere with adequate water are as likely to fail in normal growth when transferred to a low energy-high moisture area, but the failure here is due to excessive hydration. It should never be forgotten that plants which are grown as crops usually would not, if left alone, select the particular field as the place to become established. It is common experience that fields which are abandoned are soon invaded first by weeds and then later by the native plants from the fence row.

Fortunately, the habits and requirements of a species are not inflexible, but when the extreme of flexibility is attained, either the environment must be changed or the plant will fail to grow successfully. Such failure is clearly traceable not to a single plant process but rather to the general incompatibility existent between the particular physiological entity and the environment. Under such circumstances selection of new agronomic varieties of the species may result in a better adjustment.

Where plants are grown in greenhouses, it is possible to provide a species with a close replica of its natural environment. The most successful greenhouse growers are those who come closest to fitting the total plant environment to the particular physiological complex which they are hoping to produce. Outside of controlling temperature and in part sunlight, practically all the growers' attention is directed toward the proper manipulation of moisture relations. "Watering" in greenhouses is an art, the practice of which requires the most competent and observing men. The application of fertilizers is secondary in importance. That is, sufficient nutrients are provided to avoid less than adequate amounts, but above this threshold, the grower regulates the behavior of his plants by proper applications of water. The interval between applications varies from day to day, depending on cloudiness, temperature, and stage of plant growth. During the early vegetative phases of the plant cycle, other things being equal, the interval is shorter than it is later on toward the "storage" and reproductive phases. In other words, the vegetative growth of plants is pushed or forced by frequent "waterings" and checked by less frequent "waterings."

Furthermore, the nature of the internal processes of a plant growing under field conditions favoring high moisture content of tissue differ in types as well as intensities from those of plants which have entered into a drought reaction. Associated with the former is a high metabolic rate, rapid growth, rapid transpiration, rapid absorption and translocation of soil solutes, succulence of tissue, in many

plants a failure to develop a root system in proportion to the top (3), rapid expansion of the leaf area (9), and a high degree of carbohydrate utilization sometimes including various degrees of depletion of reserves previously deposited (6, 7). Coupled with these high-speed reactions are dangers against which the plant is poorly prepared. Such plants are easily battered and broken by winds. The exposed succulent tissues serve as an easy corridor of infection for rot-causing organisms. Plants with poorly developed root systems are ready victims for severe atmospheric droughts. Finally, in sugar cane, when plants in this state are harvested, even though the tonnage may be phenomenal, the water content is so high and the sugar content so low that sugar yields are distressingly poor.

On the other hand, when plants which are capable of undergoing the drought reaction are subjected to a gradual atmospheric drought or soil drought or both, they react very precisely. Metabolic processes are reduced in intensities and are even changed in nature (19, 4). Total transpiration, and even unit transpiration is reduced (14, 18), root systems are extended (3), leaf area is sharply reduced (9, 11), leaf color changes from a dark green to yellow green, cell walls become thick and hard (6), and carbohydrate reserves begin to accumulate (4). Paralleling these changes, the plant becomes less susceptible to damage by wind or sudden and severe atmospheric droughts (7). Further, when sugar cane is harvested following such hardening, even though the total plant tonnage may be lower than average, the sugar yield is relatively high.

It is cogent now to examine the feasibility of controlling sugar cane growth in Hawaii. As has already been pointed out, in greenhouses everywhere plant growth is in large part controlled by intelligent application of water. Here in Hawaii the climate is essentially a "greenhouse climate." Furthermore, of the total acreage given over to sugar cane, somewhat more than half is under partial or complete irrigation. It therefore appears, that we have here an opportunity to grow an eighth of a million acres of sugar cane using much the same precision that is used on a very few plants grown under glass. For those areas in which rainfall is a direct source of water, and especially in those areas where the rainfall is excessive, physiological methods of reducing moisture levels within the plant may be helpful.

Although it is possible for the cane grower to learn a great deal from greenhouse practice, many factors are introduced which of necessity must be considered in arriving at a proper irrigation program. Thus, in greenhouses control of relative humidity, air movement, and temperature can be mechanically effected. Soils are mixed so as to result in adequate aeration, drainage and fertility. Some of these factors may be controlled but others are outside the control of the cane grower. That the depth and nature of the soil permeated by the roots of the plant are of primary importance need not be argued, yet, the chief loss of water held by a soil planted to sugar cane is through transpiration. Thus, the factors which are involved in determining the irrigation interval are multiple and complex. On the one hand, the volume of water in the soil about the roots is the reservoir from which the plant obtains the moisture for its needs. If the soil is shallow, irrigations will need to be more frequent than if the root-permeated zone is deep. But within the limits of the soil's capacity to hold a quantity of available water, atmospheric and plant factors become the most important. These factors are numerous and diverse. The distribution and vitality (15) of the roots, the age of the crop, the leaf area of the

plant, the density of the stand, the normal transpirational idiosyncracies of the particular variety are plant factors which must figure in the nature of the irrigation program. Temperature, the intensity of sunlight, relative humidity and air movement are atmospheric factors all of which play a large part in determining the transpirational losses. Finally, it should not be forgotten that the plant may under certain conditions of unbalance between internal pressures and external conditions of temperature and humidity actually absorb water from the atmosphere (1, 16, 22).

There are two general approaches to an irrigation program. One involves the application of water at intervals, the length of which is determined in part by rule-of-thumb methods obtained through experience, and in part through criteria based upon soil and/or days or number of degrees of temperature* a crop has experienced (20). In the average year such a program generally fits well with the actual needs of the plant. But when one remembers all of the factors involved in determining the water requirements of a crop, it is apparent that any program imposed upon it which would consider all the factors in their proper proportions would be hopelessly complicated and detailed. Further, it is a rare year that is average.

The second approach to an irrigation program (9) is based upon the simple hypothesis that the moisture level of a crop at any one time is the result of the interplay of all the internal and external factors affecting the water relations of the plant as integrated by the plant itself. Thus, if it were possible to determine the moisture level of a crop under field conditions and through experimentation determine the growth behavior of the crop to particular moisture levels, it would be fairly easy to provide the necessary amount of water month by month throughout the growth cycle. This method is now being used in the experiments to be described presently, superimposed upon the day-degree method of Swezey and Denison.†

It is the purpose of this paper to report studies which have been under way for the past three and a half years. These studies have in part been directed toward an analysis of the moisture levels within the various tissues or organs of the sugar cane plant to determine their interrelationships and to obtain from these studies a tissue or organ which can be used as an "index" to the general moisture relations of the plant. In a later communication, an attempt will be made to associate the various moisture levels with the growth reactions of the plant.

It is hoped that once such a moisture index is located and adopted, it will be used extensively on the plantations where careful records will be compiled so that as time goes on we shall accumulate a background of precise information against which modifications of practices will become apparent. With this objective, it is clear that a desirable index tissue is one which is precise and at the same time readily available to the sample collector. Further, it must in its moisture variations reflect the moisture levels, not only of the growing, meristematic tissues, but also those of the mature portions of the plants.

Experimental

Sugar cane variety 31–1389 was used in these studies.‡ Plantings were made

* Swezey, J. A., and Denison, F. D.—local citation.

† Local citation.

‡ Although the numerical values obtained in these studies may not be correct for other varieties, there is no reason to believe that the relationships will not hold.

at the Waipio substation and on the uplands at Kailua on Oahu. The first plots (.25–.33 acre) at each place were planted July 28, 1938 with cane pieces selected from one field at Waipio. These first plots are called Waipio Plot A and Kailua Plot A, respectively. Plots B were planted October 28, 1938, Plots C, January 28, 1939, and Plots D, April 28, 1939. Thus, planting each series at three-month intervals should introduce the influences of time of planting on subsequent behavior. Further, the series at Waipio is in a climate of high light intensity and complete irrigation while that at Kailua is in a cloudy region where no irrigation is practiced. The rainfall for the plant crop was adequate, although most of it fell during the winter months with a short drought developing during the summer months. The actual amounts of water applied are of no moment to this paper, however, since it is concerned chiefly with internal moisture relations of the plant.

Beginning about two months after planting and continuing at intervals of about one month throughout the remainder of the 22-month-crop cycle, in the early morning hours (5:45 to 7:00 a.m.) five carefully selected plants from each plot were removed from the field and separated into their several parts as already described in previous papers (9, 10). These samples were tightly wrapped in paper or placed in large screw-capped bottles and then taken to the laboratory where the weights of the fresh tissue were recorded. The material was minced, placed on screen trays which were then placed in a drying cabinet heated to 90° C. through which a strong blast of air was forced. This temperature is safe so long as the air blast is maintained. The leaf and sheath material as well as the elongating cane and meristematic material is completely dry in from 2 to 3 hours, although more time is required for the cane samples (up to 8 to 12 hours). The dried samples were again weighed, and the moisture percentage based on the green weight was then calculated.

Data and Discussion

Although the data from the collections of all plots are used in the subsequent analyses, it seems unnecessary to record all of the data here. In order to give the reader an idea of the actual percentages obtained, the results are given for only two of the plots—Waipio Plot B (Table I), and Kailua Plot B (Table II). These tables reveal two important facts: (1) Each type of tissue or organ has its own characteristic moisture level even though it is directly attached to another tissue of a very different moisture level. For example, the elongating cane blades maintain a moisture level around a mean which is between 10 and 15 percentage points lower than that of the associated sheaths. The sheaths in turn have a considerably lower moisture level than the elongating cane to which they are attached; (2) In any given tissue or organ, the range in moisture level between conditions of extreme drought and extreme wetness is comparatively narrow. Thus, in Table I, the collection made July 26, 1940 was from a completely dried out crop ready for harvest, while that collected October 27, 1939 was taken after a period of heavy irrigations as well as rainfall, yet the range of moisture level in each tissue or organ is for the most part within 10 percentage points. It is apparent from these observations that considerable precision will be possible in considering influences of moisture levels upon the behavior of the plant.

That moisture levels of a plant are intimately associated with the growth of the

TABLE I
MOISTURE CONTENT OF PLANT PARTS—WAIPIO PLOT B
(% Green Weight)

	1939											1940					
	Feb. 13	Mar. 23	Apr. 20	May 25	June 26	July 22	Sept. 1	Sept. 29	Oct. 27	Nov. 25	Dec. 26	Feb. 1	Mar. 8	Apr. 12	May 17	June 21	July 26
Meristematic material	92.9	91.5	93.3	93.8	92.4	92.7	91.5	93.5	92.3	92.6	89.7	91.7	90.6	91.1	91.6	84.5	86.4
Spindle cluster	82.7	79.6	81.9	81.4	80.5	81.1	77.7	80.5	80.4	78.8	78.2	79.3	79.1	77.3	77.2	72.5	73.9
Elongating cane—blades	75.9	75.0	73.2	74.0	73.1	72.9	69.7	71.4	71.9	70.9	72.6	72.6	68.7	69.7	68.1	67.1	67.4
Elongating cane—sheaths	87.3	84.7	84.6	85.0	85.0	85.1	82.7	86.2	85.7	83.4	83.6	85.8	80.0	80.2	79.6	76.2	73.1
Green-leaf cane—blades	75.8	75.8	76.5	72.9	72.1	71.9	66.0	68.1	68.2	68.5	70.4	70.7	66.5	66.7	65.9	67.2	67.5
Green-leaf cane—sheaths	87.5	84.1	83.0	81.7	81.0	81.2	77.6	80.4	82.7	79.0	80.8	81.6	78.3	76.8	75.5	73.9	75.9
Elongating cane	92.9	91.9	92.4	93.0	91.8	92.2	91.0	93.0	92.1	90.7	89.7	89.6	89.4	89.3	90.0	84.4	87.7
Green-leaf cane	89.6	87.9	90.8	88.1	86.7	87.7	84.4	87.9	86.4	83.5	82.1	84.0	80.3	81.3	83.6	80.9	83.6
Top internodes				81.3	79.8	80.9	80.0	82.4	80.0	77.6	77.2	77.2	73.4	73.2	77.6	73.8	74.9
16th—3 internodes																	73.7
15th—3 internodes																	72.9
14th—3 internodes															73.5	72.4	71.8
13th—3 internodes															71.3	70.9	71.3
12th—3 internodes															70.9	71.3	72.1
11th—3 internodes														74.7	71.8	69.5	72.5
10th—3 internodes												75.8	72.9	72.6	71.9	72.4	72.6
9th—3 internodes												75.4	72.7	72.5	71.6	72.8	72.8
8th—3 internodes												74.3	72.3	72.1	71.7	71.8	72.3
7th—3 internodes									79.5	75.6	75.3	74.2	72.0	69.8	70.9	70.9	70.9
6th—3 internodes								80.2	79.1	74.9	74.6	73.5	71.5	70.8	70.4	69.6	69.8
5th—3 internodes							79.9	79.9	77.8	74.5	74.1	73.5	71.1	69.6	70.8	68.8	69.8
4th—3 internodes						79.8	78.1	78.3	77.2	73.9	73.7	74.1	69.4	69.9	69.4	68.5	69.0
3rd—3 internodes						77.5	77.0	77.7	75.3	73.0	73.9	72.9	70.7	69.6	69.4	68.4	68.9
2nd—3 internodes					77.7	76.2	75.9	76.1	76.2	72.3	72.9	72.1	70.2	69.4	69.1	68.1	68.0
1st—3 internodes			81.1	77.2	74.8	74.8	74.4	74.5	74.7	71.4	72.2	70.7	69.9	68.6	68.0	67.2	67.8

TABLE II
MOISTURE CONTENT OF PLANT PARTS—KAILUA PLOT B
(% Green Weight)

	1939											1940					
	Feb. 15	Mar. 24	Apr. 21	May 26	June 27	July 23	Sept. 2	Sept. 30	Oct. 28	Nov. 24	Dec. 27	Feb. 2	Mar. 9	Apr. 13	May 18	June 22	July 27
Meristematic material	94.7	92.8	93.8	92.0	93.0	92.4	90.9	92.8	93.2	92.5	93.3	92.2	90.8	92.7	93.2	92.9	87.5
Spindle cluster	81.5	79.9	80.5	79.8	79.8	79.8	76.0	80.9	81.4	80.3	79.6	79.5	78.8	80.3	80.9	78.8	72.7
Elongating cane—blades	79.2	77.0	74.0	73.5	71.9	72.2	69.9	70.9	72.9	74.0	73.5	74.1	72.9	73.7	73.6	71.6	70.7
Elongating cane—sheaths	89.0	85.7	84.8	83.3	81.8	83.0	79.9	83.5	84.4	84.8	84.4	84.0	80.1	83.1	83.3	80.7	77.4
Green-leaf cane—blades	79.0	76.5	74.3	74.2	73.6	73.4	69.6	67.6	70.1	69.9	72.5	73.9	70.5	73.1	72.5	70.7	71.7
Green-leaf cane—sheaths	86.3	84.3	82.4	82.3	80.4	80.4	77.5	77.6	80.5	79.5	80.5	80.4	79.8	80.7	79.2	78.0	76.8
Elongating cane	92.0	91.5	91.7	91.8	92.0	91.3	89.7	92.2	92.0	91.5	90.9	89.6	88.7	91.3	91.4	89.9	87.0
Green-leaf cane	87.8	85.7	87.3	86.7	85.5	84.7	80.2	84.8	86.9	85.9	83.0	81.6	81.4	83.8	85.6	84.5	81.6
Top internodes				79.4	77.2		74.8	76.0	77.8	79.6		76.5	75.3	73.4	76.0	74.0	76.6
15th—3 internodes																	75.8
14th—3 internodes																	73.6
13th—3 internodes																	73.6
12th—3 internodes																74.0	71.3
11th—3 internodes															75.1	74.0	69.9
10th—3 internodes															73.9	72.7	69.8
9th—3 internodes														73.7	74.6	71.7	70.2
8th—3 internodes												76.3	74.3	73.7	73.9	71.5	70.7
7th—3 internodes										77.3	77.7	75.1	73.5	73.0	72.8	71.8	71.8
6th—3 internodes									75.6	75.8	76.6	74.1	72.5	72.9	72.5	71.9	71.0
5th—3 internodes									74.6	75.8	75.4	73.6	72.3	72.9	72.2	71.4	70.7
4th—3 internodes							73.0	74.7	74.9	75.7	75.5	73.6	71.1	72.5	71.7	71.6	71.6
3rd—3 internodes						77.3	71.4	73.5	74.5	76.1	75.5	73.7	71.1	72.2	71.2	71.0	69.8
2nd—3 internodes					75.1	75.0	71.0	72.5	74.3	74.9	78.1	72.8	70.2	71.7	70.5	70.3	68.4
1st—3 internodes			80.0	77.2	72.5	74.2	69.1	72.0	74.0	73.5	71.9	71.8	69.6	68.3	66.7	69.2	65.8

plant is common knowledge. More specifically there is a good correlation between the moisture level of the elongating cane and meristem and the daily growth made. In this instance, in order to avoid the factor of temperature, Kailua plants during the summer months were selected and a highly significant correlation of +.756 was obtained between growth and moisture levels of the elongating cane and meristem. Thus, the index tissue must in its moisture variations reflect changes in the levels of the tissues which are active in growth and elongation. Further, it would be highly desirable if the same index were to give an indication of the moisture levels of the cane itself, since moisture levels there are so directly associated with quality.

The tissues which on *a priori* considerations might satisfy the requirements of a general Moisture Index are the blades or sheaths of certain leaves. These organs can be numbered and hence can be collected with a certain precision. Further, the line separating a sheath from a blade, or a sheath from the stem itself is clear, making sharp delimitation possible. For this reason, the use of the elongating cane is difficult since one can never be certain that one internode is still elongating and the adjacent one is mature. This same sort of indefiniteness applies to the meristem. Scattergrams were made using the moisture levels of the elongating cane blades, (leaves 3, 4, 5 and 6 counting the spindle leaf as No. 1), elongating cane sheaths, green-leaf cane blades (all green leaves from No. 7 on) green-leaf cane sheaths, respectively, against the moisture levels of each of the following: the whole plant, the green top alone, all the millable cane including the green-leaf cane, the elongating cane and meristem, the millable cane only for the last 12 months of growth. The scattergrams all indicated approximately linear relationships and hence, correlation coefficients were calculated in order to select the most reliable index. These correlations were made, first, for each plot at each site (Tables III and IV), then the plots at each place were combined into a single population (Tables V and VI), and finally all the plots at both places were combined (Table VII). This procedure in effect determines the applicability of the moisture level in one plot to moisture levels of other adjacent plots planted at different seasons and then to plots growing under two different climatic conditions. For a Moisture Index to be of greatest usefulness, it should indicate similar internal conditions no matter what the external conditions, and at the same time be reliable for small local populations.

An examination of Tables III and IV, representing the correlations taken from the small populations of individual plots, reveals the decided superiority of the elongating cane sheaths over the other three possible indices. One obvious way to rate the four tissues is simply to score them on the basis of the significance of the correlations of these small populations. This is done in Table VIII. It is worthy of note that the tissue most critical to growth, the elongating cane and meristem, for the most part, gives by far the best correlation with the elongating cane sheaths,—correlations of such a nature that they should have predictive value. The same possibilities exist for the "green top" and the "millable cane—last 12 months." These strong correlations are better revealed in Tables V, VI, and VII. By combining all the plots within each climatic area (Tables V and VI) we throw all of the plots, no matter when they were planted, around a common mean. By

TABLE III

CORRELATION COEFFICIENTS*—WAIPIO

(All correlations are positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant:				
Plot A	$.717^h$	$.728^h$	$.626^h$	$.586^s$
Plot B	$.820^h$	$.843^h$	$.864^h$	$.811^h$
Plot C	$.746^h$	$.755^h$	$.783^h$	$.824^h$
Plot D	$.621^h$	$.762^h$	$.731^h$	$.803^h$
Green top:				
Plot A	$.778^h$	$.805^h$	$.723^h$	$.600^s$
Plot B	$.884^h$	$.895^h$	$.892^h$	$.771^h$
Plot C	$.685^h$	$.615^h$	$.623^h$	$.650^h$
Plot D	$.661^h$	$.652^h$	$.659^h$	$.668^h$
Millable cane:				
Plot A	$.696^h$	$.692^h$	$.561^s$	$.530^s$
Plot B	$.760^h$	$.802^h$	$.817^h$	$.806^h$
Plot C	$.723^h$	$.691^h$	$.602^s$	$.648^h$
Plot D	$.669^h$	$.551^s$	$.751^h$	$.824^h$
Millable cane (last 12 months):				
Plot A	$.897^h$	$.614^s$	$.555^o$	$.372^o$
Plot B	$.855^h$	$.736^h$	$.720^s$	$.293^o$
Plot C	$.782^h$	$.881^h$	$.737^h$	$.539^o$
Plot D	$.509^o$	$.089^o$	$.562^o$	$.008^o$
Elongating cane and meristem:				
Plot A	$.703^h$	$.280^o$	$.378^o$	$.064^o$
Plot B	$.866^h$	$.776^h$	$.765^h$	$.467^o$
Plot C	$.614^s$	$.341^o$	$.158^o$	$.206^o$
Plot D	$.853^h$	$.668^h$	$.548^s$	$.423^o$

*^{h} Indicates correlation is highly significant (beyond 1% level).
^{s} Indicates correlation is significant (between 5 and 1% level).
^{o} Indicates correlation is not significant.
All significant values were obtained using $n-2$.

TABLE IV

CORRELATION COEFFICIENTS*—KAILUA

(All correlations positive except as indicated)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant:				
Plot A	$.732^h$	$.710^h$	$.508^s$	$.614^s$
Plot B	$.747^h$	$.819^h$	$.640^h$	$.662^h$
Plot C	$.573^s$	$.717^h$	$.534^s$	$.589^h$
Plot D	$.516^s$	$.428^o$	$.431^o$	$.350^o$
Green top:				
Plot A	$.789^h$	$.537^s$	$.622^s$	$.598^s$
Plot B	$.797^h$	$.742^h$	$.602^s$	$.547^s$
Plot C	$.666^h$	$.573^s$	$.619^h$	$.432^o$
Plot D	$.532^s$	$.443^o$	$.391^o$	$.237^o$
Millable cane:				
Plot A	$.747^h$	$.737^h$	$.530^s$	$.566^s$
Plot B	$.589^s$	$.705^h$	$.337^o$	$.400^o$
Plot C	$.287^o$	$.397^o$	$-.043^o$	$.236^o$
Plot D	$.411^o$	$.055^o$	$-.026^o$	$.285^o$
Millable cane (last 12 months):				
Plot A	$.640^s$	$.212^o$	$.193^o$	$.129^o$
Plot B	$.803^h$	$.338^o$	$.280^o$	$.388^o$
Plot C	$.774^h$	$.629^s$	$.407^o$	$.085^o$
Plot D	$.823^h$	$.727^s$	$.649^s$	$.449^o$
Elongating cane and meristem:				
Plot A	$.820^h$	$.461^o$	$.712^h$	$.478^o$
Plot B	$.790^h$	$.512^o$	$.478^o$	$.032^o$
Plot C	$.813^h$	$.550^s$	$.570^s$	$.231^o$
Plot D	$.832^h$	$.362^o$	$.334^o$	$.191^o$

* See footnote to Table III.

TABLE V

CORRELATION COEFFICIENTS*—COMBINED

WAIPIO PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	$.726^{h}$	$.765^{h}$	$.738^{h}$	$.764^{h}$
Green top	$.802^{h}$	$.734^{h}$	$.730^{h}$	$.689^{h}$
Millable cane	$.700^{h}$	$.681^{h}$	$.476^{h}$	$.696^{h}$
Millable cane (last 12 months).......	$.765^{h}$	$.675^{h}$	$.639^{h}$	$.334^{s}$
Elongating cane and meristem........	$.794^{h}$	$.580^{h}$	$.512^{h}$	$.311^{s}$

* See footnote to Table III.

TABLE VI

CORRELATION COEFFICIENTS*—COMBINED

KAILUA PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	$.608^{h}$	$.639^{h}$	$.508^{h}$	$.540^{h}$
Green top	$.682^{h}$	$.533^{h}$	$.502^{h}$	$.370^{h}$
Millable cane	$.472^{h}$	$.457^{h}$	$.261^{s}$	$.251^{o}$
Millable cane (last 12 months).......	$.756^{h}$	$.464^{h}$	$.359^{s}$	$.018^{o}$
Elongating cane and meristem........	$.752^{h}$	$.445^{h}$	$.474^{h}$	$.202^{o}$

* See footnote to Table III.

TABLE VII

CORRELATION COEFFICIENTS*—ALL PLOTS

(All correlations positive)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Whole plant	$.672^{h}$	$.720^{h}$	$.619^{h}$	$.632^{h}$
Green top	$.722^{h}$	$.671^{h}$	$.624^{h}$	$.577^{h}$
Millable cane	$.607^{h}$	$.589^{h}$	$.454^{h}$	$.466^{h}$
Millable cane (last 12 months).......	$.760^{h}$	$.602^{h}$	$.497^{h}$	$.222^{s}$
Elongating cane and meristem........	$.774^{h}$	$.518^{h}$	$.457^{h}$	$.250^{h}$

* See footnote to Table III.

TABLE VIII

RELATIVE MERIT OF THE POSSIBLE INDICES

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Number of correlations significant beyond 1% level (h).................	31	21	15	11
Number of correlations significant between 5% and 1% (s)..............	6	7	11	7
Number of correlations not significant.	3	12	14	22

doing this, however, the populations are increased and hence lower correlations have relatively higher significance. But considering the "green top," the "elongating cane and meristem" and the last 12 months of millable cane, the correlation coefficients with the elongating cane sheaths are of the same high actual values.

Finally, when populations are combined which were planted at different seasons and which were grown under two different climatic conditions (Table VII), the same high correlation coefficients are obtained for the elongating cane sheaths.

Examinations of these tables may cause the reader to wonder why the correla-

tions between the green-leaf cane sheaths and the "whole plant" are not given greater weight in this paper. If the index tissue is to be of value, it should have predictive value for specific tissues, the most important of which is the growing tissue. The growing tissue constitutes a very small portion of the whole plant and if an index correlates well with the whole plant but not so well with particular parts, it is of much less value than an index which correlates very well with important parts and not so well with the whole. Thus, the green-leaf cane sheaths show no significant correlation in five out of eight plots where the growing tissue was involved, yet the "whole plant" correlations are very good except for one case. On the other hand, the elongating cane sheaths show good correlations for *all* of the "whole-plant" populations even though most of the actual correlation values are somewhat less than those obtained for the green-leaf cane sheaths. Further, *all* of the elongating cane and meristem population yield materially superior correlations with the elongating cane sheaths than with the other sheaths. The same general argument may be applied to the "green top" and the "millable cane—last 12 months." These comparisons show up very well in Table VII, where the correlation values are materially higher between the three plant parts and the elongating cane sheaths than they are with any other possible index.

It is because of these comparisons, that the elongating cane sheaths are selected as the Moisture Index of the sugar cane plant. The index tissue is easy to collect, it can be removed from the plant with much precision, and it has shown itself to be reliable for small populations as well as mixtures of populations produced not only in different seasons, but also in different climatic areas. It therefore seems reasonable that a given moisture level in this index tissue reflects certain moisture levels in other parts of the plant, and this is true no matter what the age or location of the crop. One interesting variation has been noted which will appear again later on. It involves the case where a crop has suffered a prolonged drought of several months. Under this stimulus, the plants at a low metabolic level underwent the drought reaction. When in this condition, the elongating cane and meristem contained higher levels of moisture than was indicated by the Moisture Index.

Now that a moisture index tissue has been arrived at, the next phase of this study involves fitting curves to the data obtained and determining whether such curves can be of any predictive value using data from crops not involved in the construction of the curves. In this portion of the study, the level of moisture in the elongating cane sheaths will be used against the moisture levels of the elongating cane and meristem, the green top, and finally the millable cane of the last 12 months.

Elongating Cane and Meristem:

First the simple straight-line equation was calculated from the data. It was found to be $y = 85.56 + .6904\,x$. Thus, where x, the moisture level in the elongating cane sheaths, is 76.5 (coded to 1), y, the level of moisture in the elongating cane and meristem, is 86.25. And where x is 86.5 (coded to 11), y is 93.15. This line is drawn in Fig. 1. From this line, it is now possible to determine the actual goodness of fit. Plotting the actual values obtained, the resulting points are classified according to their actual departure from the line. These results are summarized in Table IX.

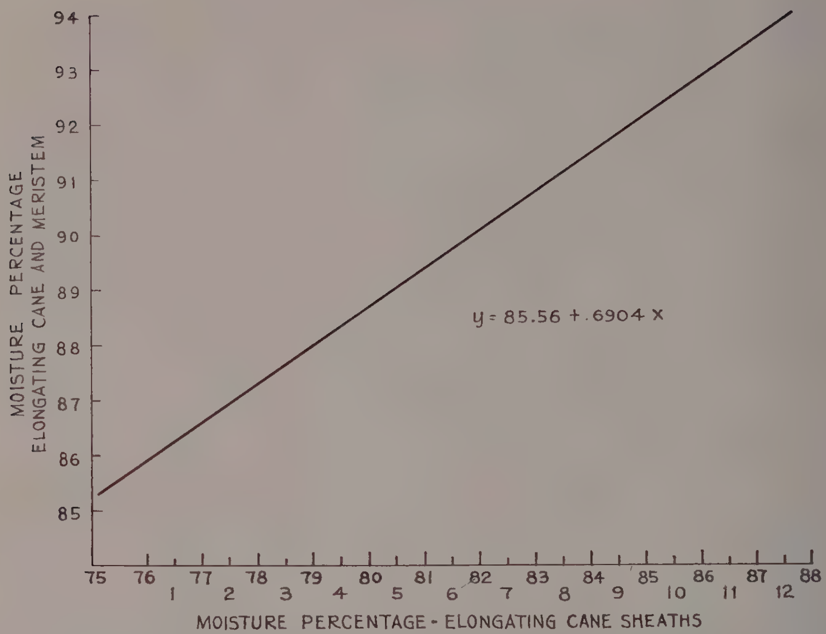

Fig. 1. Relation between moisture content of elongating cane sheaths and elongating cane and meristem.

TABLE IX

GOODNESS OF FIT TO A STRAIGHT LINE*

PLANT CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	17	27.0	23	36.5	40	31.8
1.0 percentage point	38	60.3	40	63.5	78	61.9
1.5 percentage points	53	84.1	54	85.7	107	84.9
2.0 percentage points	59	93.7	59	93.7	117	93.7
>2.0 percentage points of the observed.	63	100.0	100	100.0	126	100.0

* $y = 85.56 + .6904\,x$.

TABLE X

GOODNESS OF FIT TO A STRAIGHT LINE*

RATOON CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	12	26.7	22	48.9	34	37.8
1.0 percentage point	26	57.8	39	86.7	65	72.2
1.5 percentage points	34	75.6	41	91.1	75	83.3
2.0 percentage points	35	77.8	43	95.6	78	86.7
>2.0 percentage points of the observed.	45	100.0	45	100.0	90	100.0

* $y = 85.56 + .6904$.

It appears then, that by using a straight line, it is possible to predict about 85 per cent of the moisture levels of growing tissue to within one-and-one-half percentage points of the observed value using the moisture percentages of the corresponding elongating cane sheaths. The next step involves predicting the moisture level of the tissues from the moisture percentages of the elongating cane sheaths

not used in calculating the regression line. The data for this trial are taken from the ratoon crops grown after the plant crop. The goodness of fit is reported in Table X.

The predictions for the ratoon crop are particularly excellent for the Waipio crop where more than 90 per cent of the predictions were within 1½ percentage points of the true values. The Kailua ratoons, however, departed somewhat when predictions in ten of the cases were more than 2 percentage points away from the actual. Eight of these ten cases were collections from plants which had been exposed to a prolonged drought. In these, the moisture level of the growing cane was in all cases considerably above what could be predicted from the moisture level of the corresponding sheaths. The point is of interest. Although the plant in building a higher-than-normal moisture level in the growing tissue under drought conditions adds to its survival ability, the growth of the plant does not appear to be affected and remains slow, more in keeping with the level shown by the Moisture Index.

Even though a straight line appears to be a satisfactory fit, the actual distribution of points on the graph suggest that a portion of a parabola might give a better fit. Toward this end, the following equation was determined from the data:

$$y = 84.29 + 1.249 \times - .0443\, x^2.$$

In solving for particular points, the x values in the equation represent the moisture levels of the elongating cane sheaths and are coded as follows: 76.5=1, 77.5=2, etc. up to 87.5=12. The y values are the moisture percentages of the elongating cane and meristem. The resulting curve is shown in Fig. 2.

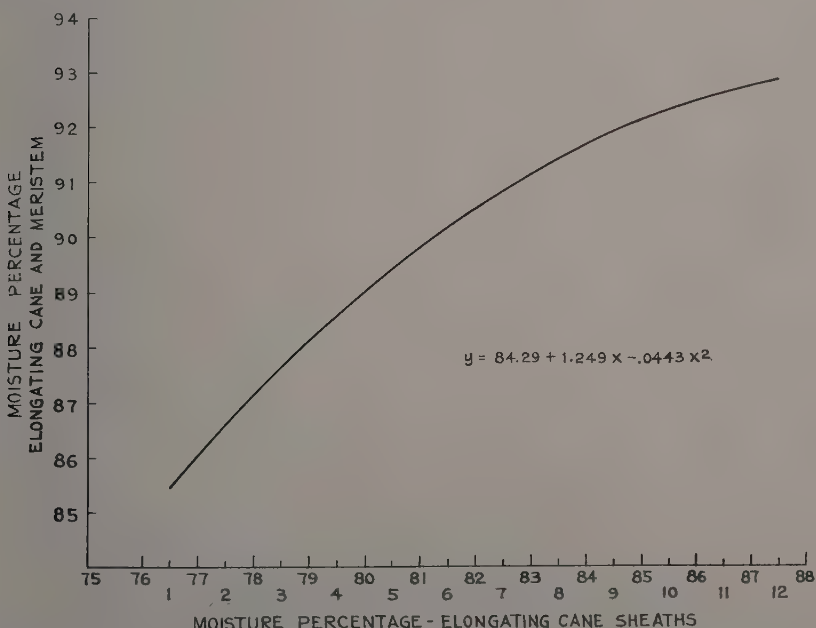

Fig. 2. Relation between moisture content of elongating cane sheaths and elongating cane and meristem.

Again the goodness of fit is recorded for the plant crop in Table XI and for the ratoon crop in Table XII.

TABLE XI
GOODNESS OF FIT TO A CURVE*
PLANT CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua No.	Kailua %	Waipio No.	Waipio %	Total No.	Total %
0.5 percentage point	18	28.6	23	36.5	41	32.5
1.0 percentage point	44	69.8	41	65.1	85	67.4
1.5 percentage points	55	87.3	58	92.1	113	89.7
2.0 percentage points	62	98.4	60	95.2	122	96.8
>2.0 percentage points of the observed	63	100.0	63	100.0	126	100.0

* $y = 84.29 + 1.249 \times -.0443\ x^2$.

TABLE XII
GOODNESS OF FIT TO A CURVE*
RATOON CROP

Moisture percentages of the elongating cane and meristem predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua No.	Kailua %	Waipio No.	Waipio %	Total No.	Total %
0.5 percentage point	18	40.0	18	40.0	36	40.0
1.0 percentage point	33	73.3	40	88.9	73	81.1
1.5 percentage points	35	77.8	43	95.6	78	86.7
2.0 percentage points	36	80.0	43	95.6	79	87.8
>2.0 percentage points of the observed	45	100.0	45	100.0	90	100.0

* $y = 84.29 + 1.249 \times -.0443\ x^2$.

When the last column of Table XI is compared with that of Table IX, there appears to be a slight improvement in the fitting. From Table XII, it may be observed that the ratoon crop can be predicted with considerable accuracy. Whether it will be better to use a straight line or a curve can best be determined at a later date when a much larger number of observations have been made. To be sure, from the point of view of the fieldman, it will not be necessary to use such a curve at all, since if it is known that a relationship exists between the moisture level of the sheaths and that of the growing tissue, one need only concern himself with maintaining the level in the sheaths in one range during growth activity and in another during maturation of the crop. At the present stage, it appears that for variety 31–1389, the range in moisture level of the sheaths associated with rapid growth is between 83.5 and 85.5. Values above 85.5 appear to indicate overwatering. Growth curtailing begins when the index drops to about 82.5 per cent and becomes more severe as the index drops. The lowest value for the Moisture Index so far observed in field-grown plants was 76.2 per cent; the highest, 88.6 per cent.

Green Top:

To predict the moisture level of the whole green top from the level of moisture of the elongating cane sheaths requires a new equation. By calculation, it is found to be

$$y = 74.5844 + .7606\ x$$

where $x=1$ (76.5%) $y=75.35$ and where $x=11$ (86.5%) $y=82.95$. In Table

XIII, the goodness of fit is reported for the plant crop from which the equation was calculated and in Table XIV, a similar tabulation is recorded for the ratoon crop which did not enter into the calculation of the equation.

TABLE XIII

GOODNESS OF FIT TO A STRAIGHT LINE*

PLANT CROP

Moisture percentages of the green top predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	25.3	20	28.2	38	26.7
1.0 percentage point	44	62.0	33	46.5	77	54.3
1.5 percentage points	59	83.1	40	56.9	99	70.0
2.0 percentage points	60	84.4	51	71.8	111	78.1
>2.0 percentage points of the observed	71	100.0	71	100.0	142	100.0

* $y = 74.5844 + .7606\,x$.

TABLE XIV

GOODNESS OF FIT TO A STRAIGHT LINE*

RATOON CROP

Moisture percentages of the green top predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	18	40.0	14	31.1	32	35.6
1.0 percentage point	24	53.3	25	55.6	49	54.4
1.5 percentage points	35	77.8	31	68.9	66	73.3
2.0 percentage points	37	82.2	34	75.6	71	78.9
>2.0 percentage points of the observed	45	100.0	45	100.0	90	100.0

* $y = 74.5844 + .7606\,x$.

It is clear that even so diverse a collection of tissues as is found in the green top can be successfully correlated with the index chosen. The predictions for the ratoon are fully as good as for the plant crop. However, the fit is not so good as was observed for the elongating cane and meristem. The greater departure in this case is to be expected, however, since there is such a large diversity of tissues involved. However, when it is possible to estimate the moisture percentage of over 70 per cent of the population to within one-and-one-half percentage points, it clearly indicates considerable precision.

Attempts to fit other equations to the population resulted in a straight line each time.

Millable Cane—Last 12 Months:

The fieldman is seriously concerned with the moisture content of the millable cane since good quality ratios are associated with low moisture content. At first it was hoped that the millable cane including the green-leaf cane could be correlated successfully with the sheaths from the very beginning of the crop, but Tables III and IV indicate no high degree of reliability. The reason for this is quite clear when it is remembered that in the young stage, the succulent green-leaf cane makes up a very large part of the whole cane. However, since the fieldman's real concern centers around the crop as it approaches harvest, an effort was made to determine the correlations for the last 12 months of the cane. That is, for a 22-month crop, the correlations were begun when the crop was 10 months old. Now, if one is

growing a short-cycle crop, he should still begin not earlier than 10 months. But even so he would still have from 2 to 6 months in which to control the moisture levels.

Reference to Tables III-VII indicates a good correlation between the moisture level of the "millable cane—last 12 months" and the moisture level of the Moisture Index, the elongating cane sheaths. The straight-line equation for this relationship is

$$y = 69.81 + .753\,x$$

where x=1 (76.5), y=70.56 and where x=11 (86.5), y=78.84. Plotting the data obtained for the plant crop results in a fair degree of precision (Table XV). The fit for the ratoon crop is poor (Table XVI). The next attempt was to fit a curve to the data. The equation obtained is

$$y = 71.8 - .1658x + .0766\,x^2.$$

TABLE XV

GOODNESS OF FIT TO A STRAIGHT LINE*

PLANT CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	11	25.0	7	15.9	18	20.5
1.0 percentage point	21	47.7	12	27.3	23	37.5
1.5 percentage points	26	59.1	23	52.3	49	55.7
2.0 percentage points	37	84.1	33	75.0	70	79.6
>2.0 percentage points of the observed	44	100.0	44	100.0	88	100.0

* $y = 69.81 + .753\,x$.

TABLE XVI

GOODNESS OF FIT TO A STRAIGHT LINE*

RATOON CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point	1	5.8	4	23.5	5	14.7
1.0 percentage point	3	17.6	7	41.2	10	29.4
1.5 percentage points	6	35.3	8	47.1	14	41.2
2.0 percentage points	13	76.5	10	58.8	23	67.7
>2.0 percentage points of the observed	17	100.0	17	100.0	34	100.0

* $y = 69.81 + .753\,x$.

Plotting the data against this curve (Fig. 3) results in a material improvement in the goodness of fit, both for the plant crop (Table XVII) and the ratoon crop (Table XVIII). Thus, in the plant crop, 27.3 per cent of the cases were within 0.5 percentage point of the observed, 60.2 per cent of the cases were within 1.0 per cent and 79.5 per cent were within 1.5 percentage points of the observed. Although the ratoon crop at Kailua fits well, that grown at Waipio departed from predictions even though more than half of the cases fell within 1.5 percentage points of the observed. Perhaps as time goes on and more data are available it will be possible to draw curves for each island area, and in this way achieve a higher order of precision.

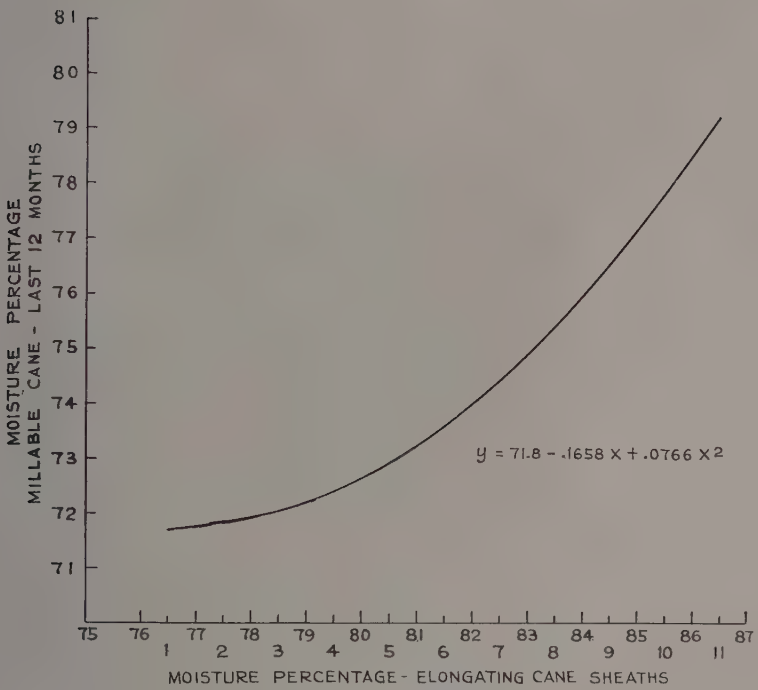

Fig. 3. Relation between moisture content of elongating cane sheaths and "millable cane—last 12 months."

CONCLUSION

As a result of these correlations, it is safe to conclude that the moisture level of the elongating cane sheaths is a true index to the moisture levels of the growing tissues of the cane plant as well as of the mature millable cane. Since it has been shown that the Moisture Index is reliable not only for small local plots but also for plots started at different times of the year, and in different climatic areas, it is safe to presume that the level of moisture observed is the result of the integration by the plant of all factors, external and internal, affecting its moisture relations. Consequently, it is reasonable to suppose that the irrigation program will best fit a particular crop if it is based upon a running picture of the conditions within the plant as portrayed by the Moisture Index.

TABLE XVII

GOODNESS OF FIT TO A CURVE*

PLANT CROP

Moisture percentages of the millable cane—last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua		Waipio		Total	
	No.	%	No.	%	No.	%
0.5 percentage point of the observed....	13	29.5	11	25.0	24	27.3
1.0 percentage point of the observed....	31	70.5	22	50.0	53	60.2
1.5 percentage points of the observed...	36	81.8	34	77.3	70	79.5
2.0 percentage points of the observed...	37	84.1	39	88.6	76	86.3
2.0 percentage points of the observed...	44	100.0	44	100.0	88	100.0

* $y = 71.8 - .1658\, x + .0766\, x^2$.

TABLE XVIII

GOODNESS OF FIT TO A CURVE*

RATOON CROP

Moisture percentages of the millable cane last 12 months predicted from the moisture percentages of the corresponding elongating cane sheaths falling within	Kailua No.	Kailua %	Waipio No.	Waipio %	Total No.	Total %
0.5 percentage point of the observed....	4	23.5	3	17.6	7	20.6
1.0 percentage point of the observed....	8	47.1	7	41.2	15	44.1
1.5 percentage points of the observed...	13	76.5	9	52.9	22	64.7
2.0 percentage points of the observed...	13	76.5	11	64.7	24	70.6
2.0 percentage points of the observed...	17	100.0	17	100.0	34	100.0

* $y = 71.8 - .1658\,x + .0766\,x^2$.

Summary

1. The moisture relations of eight plantings of sugar cane are analyzed and discussed.
2. The elongating cane sheaths are shown to be the most reliable tissue to be used as a Moisture Index.
3. Satisfactory correlations are found between the levels of the Moisture Index and the green top of the plant, the elongating cane and meristem, and the mature cane, respectively.
4. Curves and/or straight lines are fitted to the data and from these, the moisture levels of tissues of the ratoon crops are predicted. The predicted values fall sufficiently close to observed values to be used in determining a practical irrigation program.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 22, 1941, TO DECEMBER 1, 1941

Date	Per pound	Per ton	Remarks
Sept. 22, 1941.......	3.53¢	$70.60	Philippines.
Oct. 17............	3.51	70.20	Cubas.
" 21............	3.53	70.60	Philippines.
" 24............	3.57	71.40	Philippines.
Dec. 1............	3.51	70.20	

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